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Sudden Impulses Observed in the Magnetosphere During The Lifetime of Explorer 12, 16 August to 6 December, 1961

OBSERVATIONS OF SUDDEN IMPULSES
in the
MAGNETOSPHERE OBTAINED
from
EXPLORER XII DATA

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ABSTRACT

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A

Explorer XII magnetic records show that a positive sudden impulse on the ground is accompanied by an increase in the field strength within the magnetosphere, and hence, by a compression of the magnetosphere. Similarly, a negative sudden impulse on the ground is associated with a decrease in the field strength and an outward motion of the magnetospheric boundary. The speed of propagation of the field variations through the magnetosphere seems to be close to the hydromagnetic wave speed, although the ray-theory is not applicable.

AUTHOR

INTRODUCTION

The successful operation of the flux-gate magnetometer on board the Explorer XII earth satellite has afforded the opportunity of looking closely into the origin of the temporal variations in the geomagnetic field. The present paper reports a preliminary outcome of such a study concerned with "sudden impulses".

A "sudden impulse" is understood here as a sudden change in the geomagnetic field that takes place almost simultaneously all over the world. (Since the morphology of such changes is independent of whether the change is impulse-shaped or not, it seems meaningless to limit a "sudden impulse" literally to an impulse-like change. In fact, most of these changes look rather like a step function.) The form of each sudden impulse can be analyzed into three parts: The main part appears everywhere on the ground, while the second and the third parts appear only at a certain local time and latitude. According to whether the main part is an increase or a decrease in the horizontal component, sudden impulses are classified as "positive" or "negative", respectively. Except for the difference in sign, positive and negative sudden impulses are identical in the ground morphology. Positive sudden impulses are found almost every day, while negative ones occur about half as often. Storm sudden commencements (ssc's) and sudden impulses (si's) are morphologically quite

similar, the only difference on the ground being that an ssc precedes a magnetic storm while an si does not (Nishida and Jacobs, 1962 a, b).

The similarity in the ground morphology between ssc and si indicates that these are caused by the same mechanism. Thus the main part (i.e. world-wide part) of a positive si has been attributed to a compression of the magnetosphere due to an enhancement in the pressure of the solar wind (Chapman and Ferraro, 1931). Analogously, the main part of a negative si can be attributed to an expansion of the magnetosphere due to the diminution in the pressure of the solar wind (Nishida, 1962). The compression or the expansion starts at the boundary of the magnetosphere, and is considered as propagated throughout the interior of the magnetosphere by hydromagnetic waves (Dessler and Parker, 1959). It has recently been suggested that, in addition to pressure, the solar wind exerts a viscous-like force on the magnetosphere (Axford and Hines, 1961; Wilson and Sugiura, 1961) and attempts are made to attribute the local time dependent part of si to the deformation of the magnetosphere due to viscous-like interactions (Wilson and Sugiura, 1961; Nishida, 1962). The local time dependent part of si has been primarily attributed to the ionospheric currents (e. g. Obayashi and Jacobs, 1957; Vestine and Kern, 1962).

The apogee of Explorer XII was 83×10^3 km (in geocentric distance), and the magnetic data were transmitted when the satellite was farther than 20×10^3 km from the center of the earth. The satellite was in operation from August 16, 1961 to December 6, 1961. During this period, the apogee drifted westward from 2.5° east of the noon meridian with a rate of about 1° a day. The orbital plane was inclined to the equatorial plane by 33°. In short, most of the data are obtained at a geocentric distance of three to thirteen earth radii (abbreviated as R_e) above the morning side of the low latitude region. Reported here are observational results obtained inside or around the boundary of the magnetosphere. Originally, the magnetic field was measured about three times a second. But to reduce the error, averages over ten seconds were computed. These averages have an error of less the $\pm$ 7 gammas. Further details of data processing and accuracy are discussed by Cahill and Amazeen, (1963) and Cahill and Patel, (1964).

OBSERVATIONAL RESULTS

Plotted in Figure 1 is the magnetic flux density, B, observed by the satellite around the onset of a succession of si's on October 29, 1961. These si's are shown in Figure 2 in normal magnetograms from four widely separated ground stations. (Only the horizontal component record is reproduced, since si appear predominantly in this component

in middle and low latitudes.) The geomagnetic main field at the position of the satellite was computed using coefficients given by Jensen and Cain, (1962), and is also illustrated in Figure 1. The difference, $\triangle B$, between the observed field and the main field is plotted in Figure 3 for the whole interval of these si's. During this interval, the satellite was inside the magnetosphere and ascended from 37×10^3 km to 57×10^3 km. On the plot of $\triangle B$, the trace of the horizontal component, rapid-run magnetogram from the Honolulu observatory (geomagnetic lat. 21.0^o N, geomagnetic long. 266.4^o) is superimposed with the same scale. A definite peak to peak correspondence can be seen between the satellite and ground records.

More satellite records at time when si's are observed on the ground are presented in the following, along with the record from the Honolulu observatory. (The Honolulu record can be regarded as showing the world-wide features of the events, since si's at Honolulu happen to consist here only of the main, world-wide part in all the cases presented here.) These samples are intended to represent the shape of the field change at various regions in the magnetosphere. Positions of the satellite when these records were taken are shown in Figure 4. Figure 5 through 7 show the satellite record at times of positive si, and Figure 8

through 10 show these at times of negative si. Records of si from representative ground stations are presented in Figure 11 and 12 for si's of Figures 5 and 8. (For the rest of the cases, similar ground records are omitted.) Irrespective of the height or the local time of the satellite, it can be seen that si's appear also in satellite records, with small time discordance and with the same sign, when the satellite is inside the magnetosphere. The close similarity between the characteristics of positive and negative si's is noted here as well.

Next two records are obtained in the vicinity of the magnetospheric boundary. In both cases, the satellite is outbound with a speed of approximately 1.3 km/sec. In the case shown in Figure 13, the satellite is inside the magnetosphere at the onset of a positive si. With the advent of this si, the field strength starts to increase as in other cases previously shown. However, about three minutes later, a sharp transition in the direction of the field which is characteristic of the boundary crossing (Cahill and Amazeen, 1963), is observed, and the similarity between the satellite and the ground records is lost. In the other case shown in Figure 14, the satellite is outside the magnetospheric boundary until, around the end of a negative si, it finds itself again within the magnetosphere. Since

the satellite is outbound, this can only happen when the magnetospheric boundary moves outward. Hence, this record testifies the expansion of the magnetosphere associated with a negative si.

These figures demonstrate the contraction of the magnetosphere at the time of positive si, and its expansion at the time of negative si. Data of ssc are not available inside the magnetosphere from Explorer XII, but from the close similarity between ssc and si on the ground, it seems safe to say that the contraction of the magnetosphere takes place also at the time of ssc. Although vectors of si are analyzed into longitudinal and transverse components, results are not presented here since the magnitude of transverse component is much smaller than the error of data. It is planned to repeat this analysis when the more accurate data, which is now being prepared, becomes available.

DISCUSSION

The increase in B at the time of a positive si, or the decrease in B at the time of a negative si, takes place in a certain interval of time, (referred to hereafter as the "time scale" of the si). It is noted in the preceding records that this time scale does not depend singificantly on the height of the observation;

it is several minutes long both at the satellite level and on the ground. This is the case even when the satellite is in the close vicinity of the magnetospheric boundary, as manifested by the case of September 30, shown in Figure 13. Hence, the time scale of a si seems to be the length of time in which the contracting or the expanding motion of the magnetospheric boundary takes place. It is interesting to note that this time scale is nearly the same for all si's studied, positive or negative.

The magnitudes of si's studied here are less than one third of the field strength which existed before the onset of the change. Hence, the effect of the boundary motion is evidently propagated as an infinitesimal hydromagnetic wave through the point of observation. In most parts of the magnetosphere the wave length of a hydromagnetic wave, with a time scale of several minutes, is much greater than the scale heights of variation in the hydromagnetic wave velocity. At the height of 5×10^3 km, for example, the Alfven speed is about 2×10^3 km/sec and it varies with a scale height of 1.5×10^4 km (Francis, et al, 1959). The propagation of such long waves cannot be discussed in terms of a ray theory, as attempted by Francis et al (1959). In the case of the positive si on August 27, Figure 5, both satellite and Honolulu are near the sub-solar point. The average

speed of propagation of the wave between $7R_e$ and $1R_e$ is roughly estimated from this record as about 10^3 km/sec, which is close to Alfven wave speed in this region.

In the vicinity of the boundary, it frequently happens that the field strength is about twenty or thirty gammas (Cahill and Patel, 1964). In regions of such low field strength si's and ssc's of larger mangitude are expected to propagate as non-linear waves, and for positive si's and ssc's, these waves would become shock waves. Hence it may be possible to relate certain features of positive si's and ssc's of larger magnitude to characteristics of shock waves in the outer magnetosphere. However, it is difficult to explain the local time dependent part of si's and ssc's by this idea, as tried by Singer (1957) and Vestine and Kern (1962), because the LT dependent part appears in the same way both for positive and negative si's.

To discuss the relative magnitudes of si at various points within the magnetosphere, it is necessary to know the daily variation of si at Honolulu. Since the variation seems to be diurnal with maximum around noon and minimum around midnight, we assume an equation

$$H = Ho\ (1 - k \cos t)$$

to express si magnitude at Honolulu at local time t (measured in degrees with 0° at 0^h LT and 180° at 12^h LT). k is a

constant, and Ho designates the size of each event. In two of the cases presented here, viz., August 27 and September 22, satellite positions were nearly the same: Latitudes are $+2^{o}$ and $+6^{o}$, local times are $11^{h}40^{m}$ and $13^{h}30^{m}$, and geocentric distances are 47 and 49 x 10^{3} km. Hence it is assumed that magnitude of si, at the satellite, relative to the ground is identical in these two cases. Then it follows that k is 0.45, and that si magnitude at these positions is 2.3Ho, i.e. 2.3 times of its magnitude which would be observed at Honolulu if the local time there were 6^{h} or 18^{h}. The relative magnitudes of si at various observing points are shown in Figure 15 in the unit of Ho.

Now let us assume that the magnetospheric boundary can well be approximated by a plane surface located at the geocentric distance R on the sunward side of the earth. The magnetic field due to the boundary current can then be represented by an image of the geomagnetic dipole with respect to this plane. At point r on the earth-sun line, the strength of the image field is $M(2R-r)^{-3}$, where M is the geomagnetic dipole moment. If the position of the boundary plane changes from R to $R-\Delta R$, the image field at r then increases by $6M\,\Delta R(2R-r)^{-4}$. According to the observation by Explorer XII, the magnetospheric boundary lies generally around $10R_{e}$ (Cahill and Amazeen 1963).

Taking this distance as R, the ratio of si magnitudes at the satellite altitude ($\sim 7R_e$) to that at the sub-solare point on the ground is expected to be about 4.5. This value is about three times larger than the observed ratio. This discrepancy demonstrates that the boundary cannot be approximated by a plane, and that a single image dipole cannot duly represent magnetic field produced by the boundary current.

The level of B before the onset of si is supposed to represent the effect of the ring current and the boundary current in the quiet state. However, interpretation of the magnetometer results as absolute measurements must be done with considerable caution, and further interpretation of this level is delayed until a later paper.

ACKNOWLEDGEMENT

We should like to express our sincere gratitude to Mr. V. L. Patel for his efforts to make present data available and for his useful advice. We acknowledge also the assistance of the U. S. Coast and Geodetic Survey in providing the ground magnetic records.

FIGURE CAPTIONS

L. Ten seconds averages of the magnetic flux density observed by Explorer XII around the onset of a succession of sudden impulses on October 29, 1961. The strength of the geomagnetic main field at satellite positions, computed using Jensen and Cain's coefficients, is also given.

2. A succession of sudden impulses on October 29, 1961 recorded at four representative ground observatories; San Juan (abbreviated as SJ: Geomagnetic latitude: 29.9°N, Geomagnetic longitude: 3.2°), Trelew (TR: 31.7°S, 3.2°) Kakioka (KA: 26.0°N, 206.1°) and Toolangi (TO: 46.7°S, 220.8°.

3. Field fluctuations observed by the Explorer XII during the whole interval of sudden impulses shown in Figure 2 (ΔB is the deviation of the observed field above the main field). Horizontal component magnetograms from Honolulu are superposed with the same scale and at an arbitrary level. The position of the satellite (latitude, longitude and geocentric distance) during this interval, and the strength of the main field (abbreviated as J. C. Field) at this position are written.

4. Position (L value and local time) of Explorer XII where present data are obtained. The latitude is less than 32°.

5. Ten seconds averages of the deviation of the observed magnetic field over the geomagnetic main field around the positive sudden impulse on August 27, 1961. Honolulu horizontal component magnetogram is superposed. Written below are the satellite position, the strength of the main field and the approximate formula to get LT (at the Explorer XII positions and at Honolulu from GMT).

6. Magnetic record of Explorer XII around the positive si on November 18, 1961, illustrated in the same way as Figure 5.

7. Magnetic record of Explorer XII around the positive si on December 1, 1961, illustrated in the same way as Figure 5.

8. Magnetic record of Explorer XII around the negative si on September 22, 1961, illustrated in the same way as Figure 5.

9. Magnetic record of Explorer XII around the negative si on October 8, 1961, illustrated in the same way as Figure 5.

10. Magnetic record of Explorer XII around the negative si on October 9, 1961, illustrated in the same way as Figure 5.

11. Representative ground magnetograms (horizontal component) showing the positive si on August 27, 1961.

12. Representative ground magnetograms showing the negative si on September 22, 1961.

13. Satellite magnetic record obtained near the magnetospheric boundary around the positive si on September 30, 1961. α and ψ define the direction of the magnetic field in a manner described by Cahill and Amazeen (1963). Horizontal component magnetogram of Honolulu is superposed.

14. Satellite magnetic record obtained near the magnetospheric boundary around the negative sudden impulse on August 18, 1961.

15. Magnitude of si in various regions of the magnetosphere relative to the ground as represented by Honolulu written in the parenthesis is the latitude of each position. Ground is represented by Honolulu.

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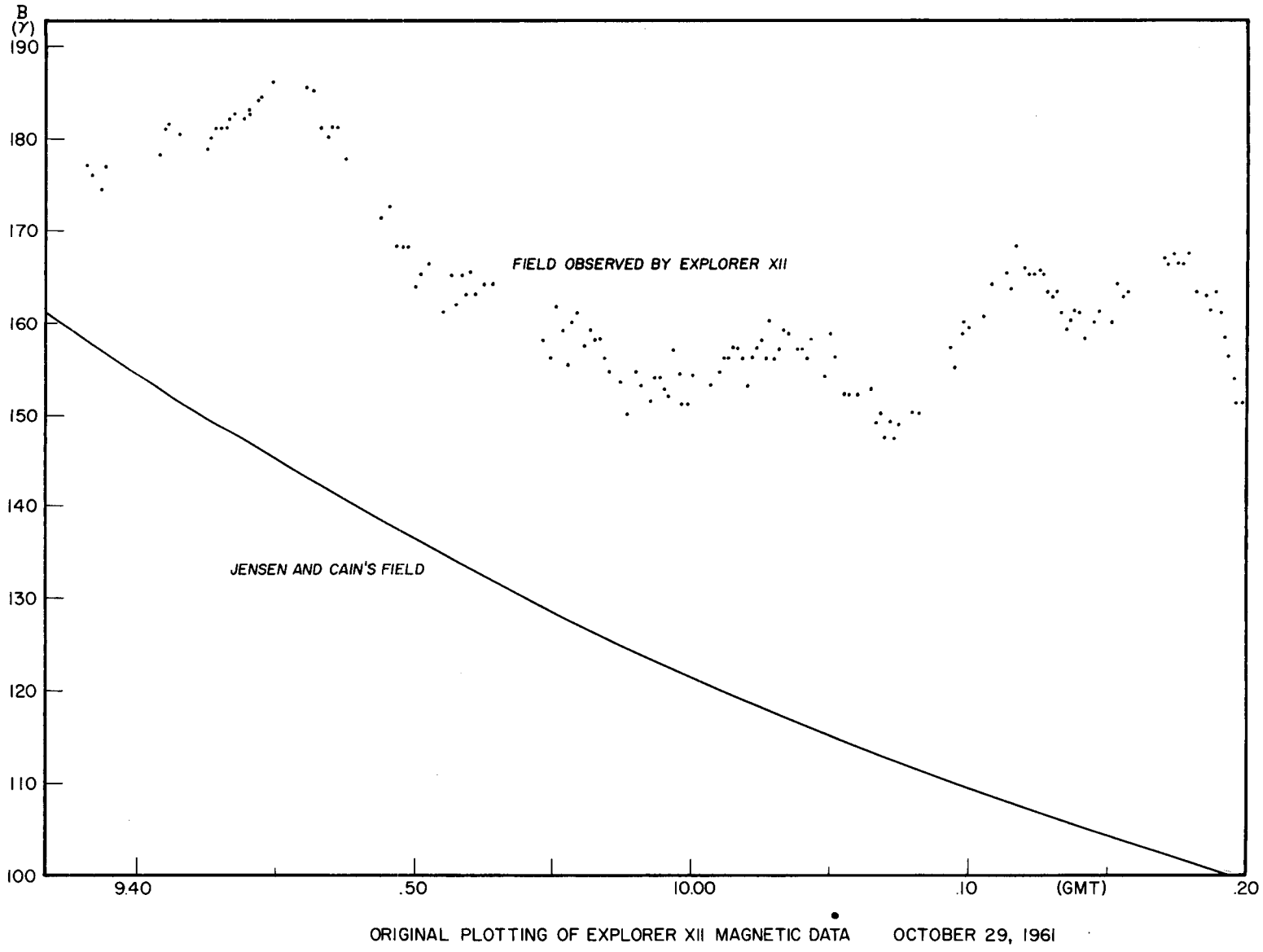

B
(γ)
190
180
170
160
150
140
130
120
110
100
FIELD OBSERVED BY EXPLORER XII
JENSEN AND CAIN'S FIELD
9.40
.50
10.00
.10
(GMT)
.20
ORIGINAL PLOTTING OF EXPLORER XII MAGNETIC DATA OCTOBER 29, 1961

Figure 1

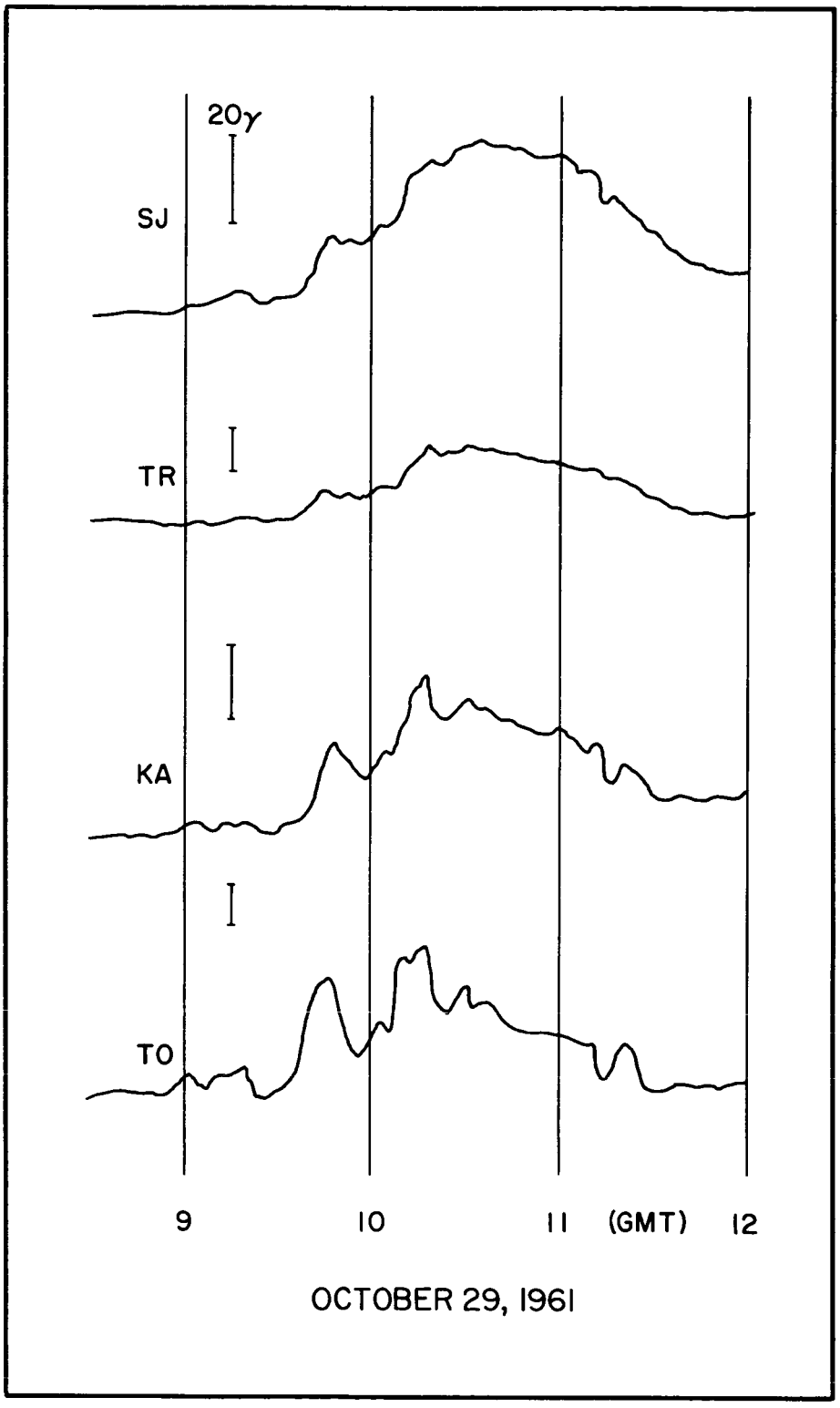


Figure 2

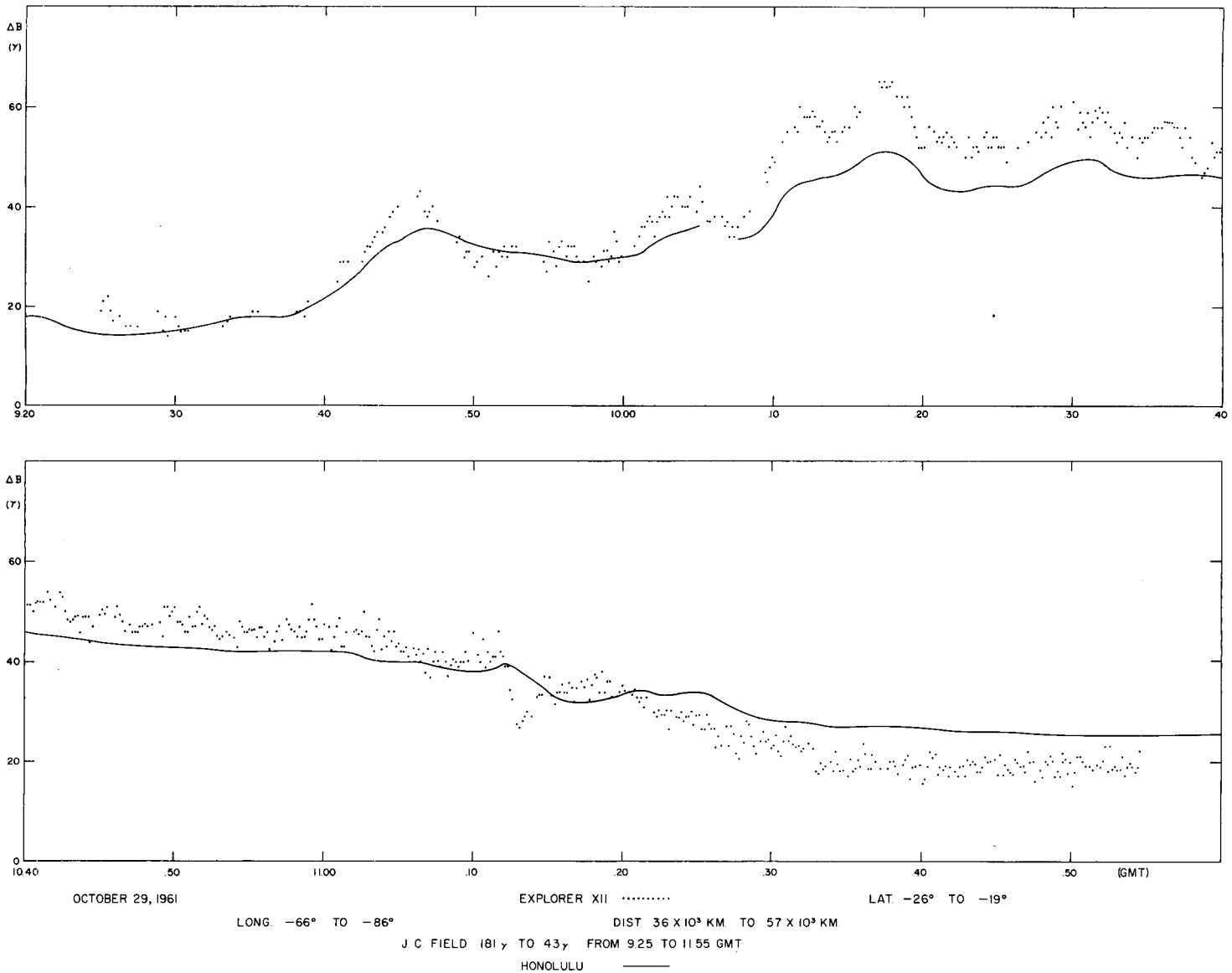

ΔB
(γ)
60
40
20
0
9.20
30
.40
.50
10.00
.10
.20
.30
.40
ΔB
(γ)
60
40
20
0
10.40
.50
11.00
.10
.20
.30
.40
.50
(GMT)
OCTOBER 29, 1961
EXPLORER XII
LAT. −26° TO −19°
LONG. −66° TO −86°
DIST. 36 X 10³ KM. TO 57 X 10³ KM.
J. C. FIELD 181γ TO 43γ FROM 9.25 TO 11.55 GMT
HONOLULU

Figure 3

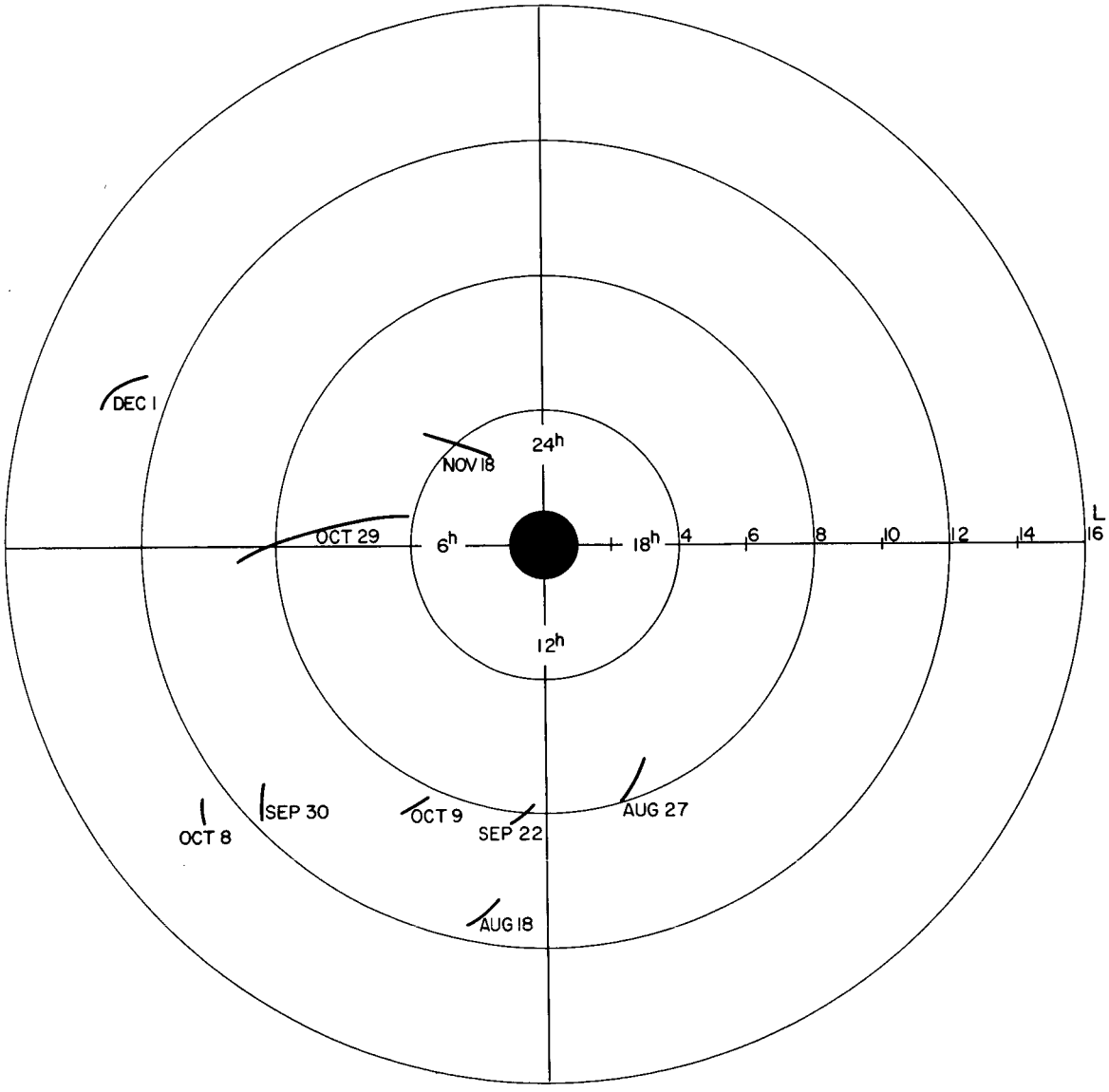
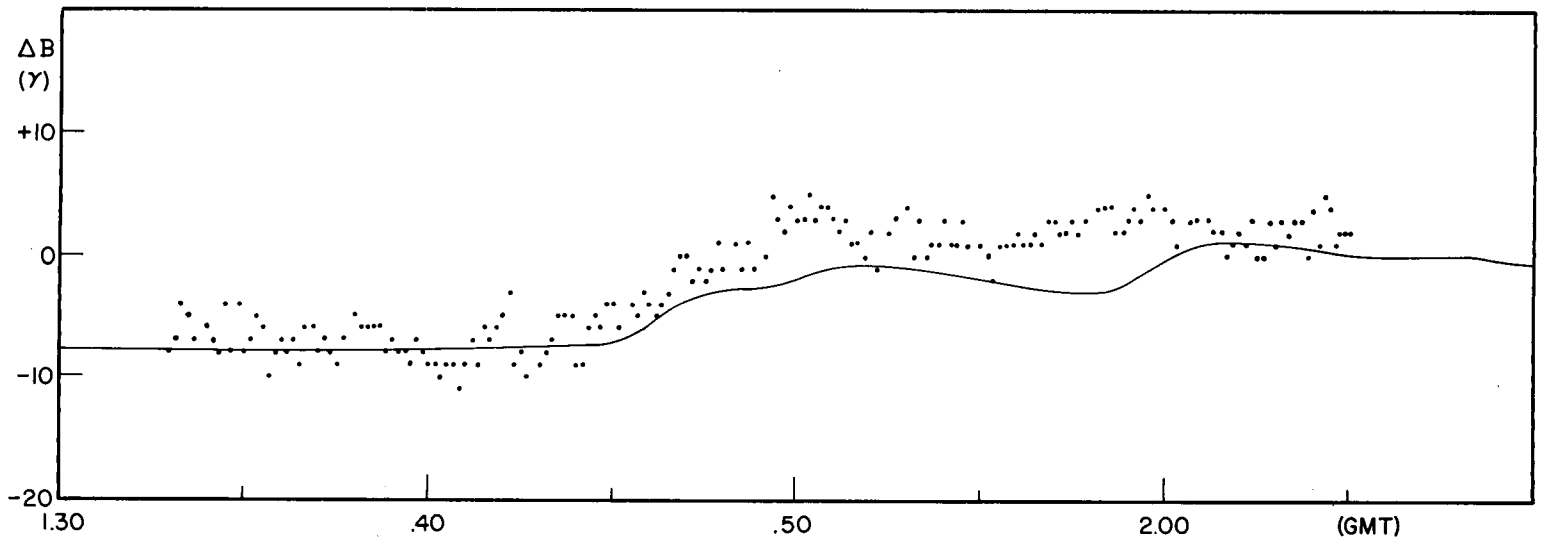

DEC 1
NOV 18
24h
OCT 29
6h
18h
4
6
8
10
12
14
L
16
12h
OCT 8
SEP 30
OCT 9
SEP 22
AUG 27
AUG 18

Figure 4



AUGUST 27, 1961 LAT. +2°, LONG. +172°, DIST. 49 X 10^3 KM., J.C. FIELD 70 γ AT 1.45 GMT

Explorer XII ····· LT = GMT + 11^h

Honolulu ——— LT = GMT − 11^h

Figure 5

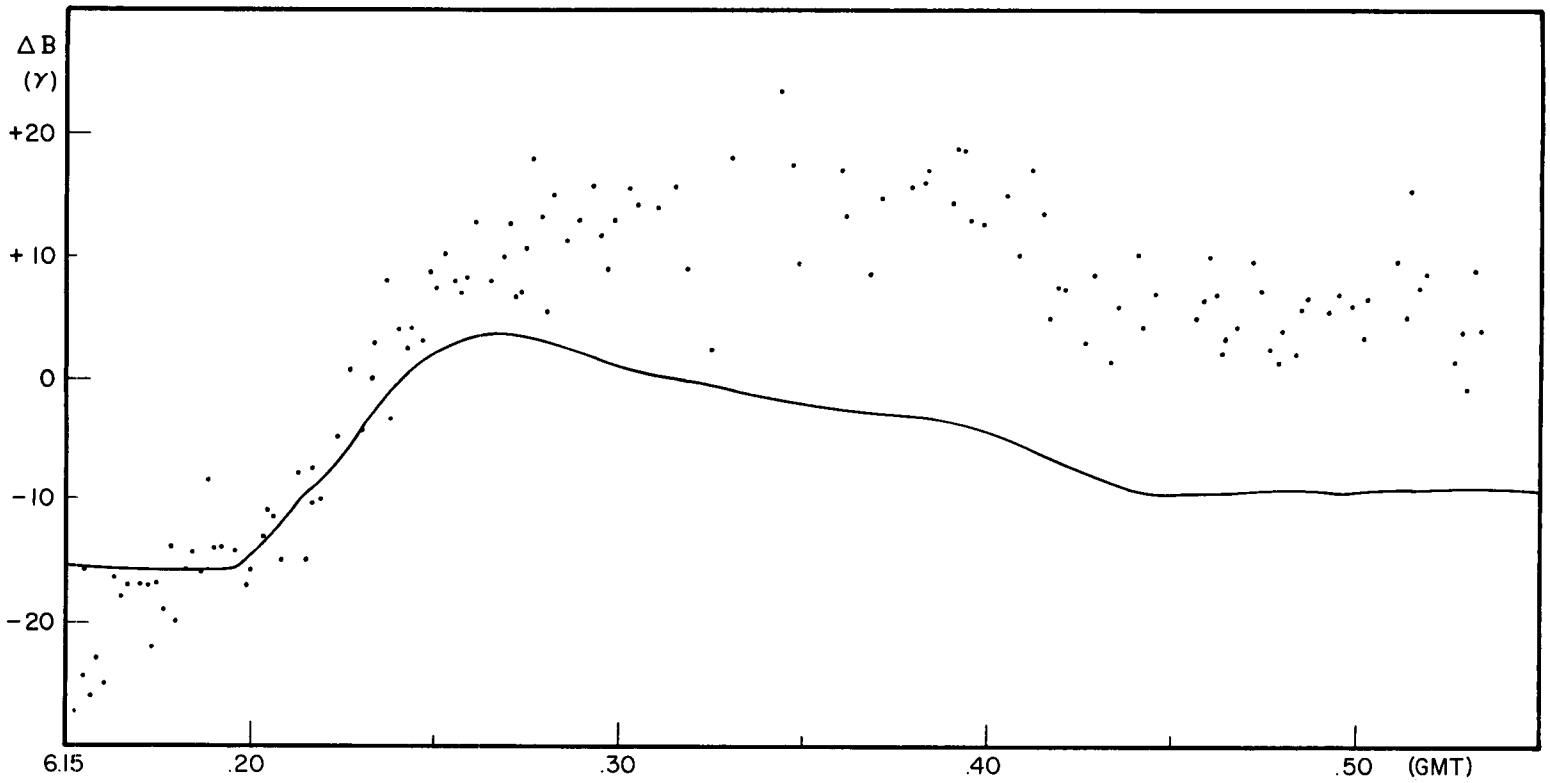

ΔB
(γ)
+20
+10
0
-10
-20
6.15
.20
.30
.40
.50
(GMT)
NOVEMBER 18, 1961
LAT. -32°, LONG. -64°, DIST. 21X10³ KM. J.C. FIELD 950γ AT 6.20 GMT
Explorer XII
LT = GMT -4h
Honolulu
LT = GMT -11h

Figure 6

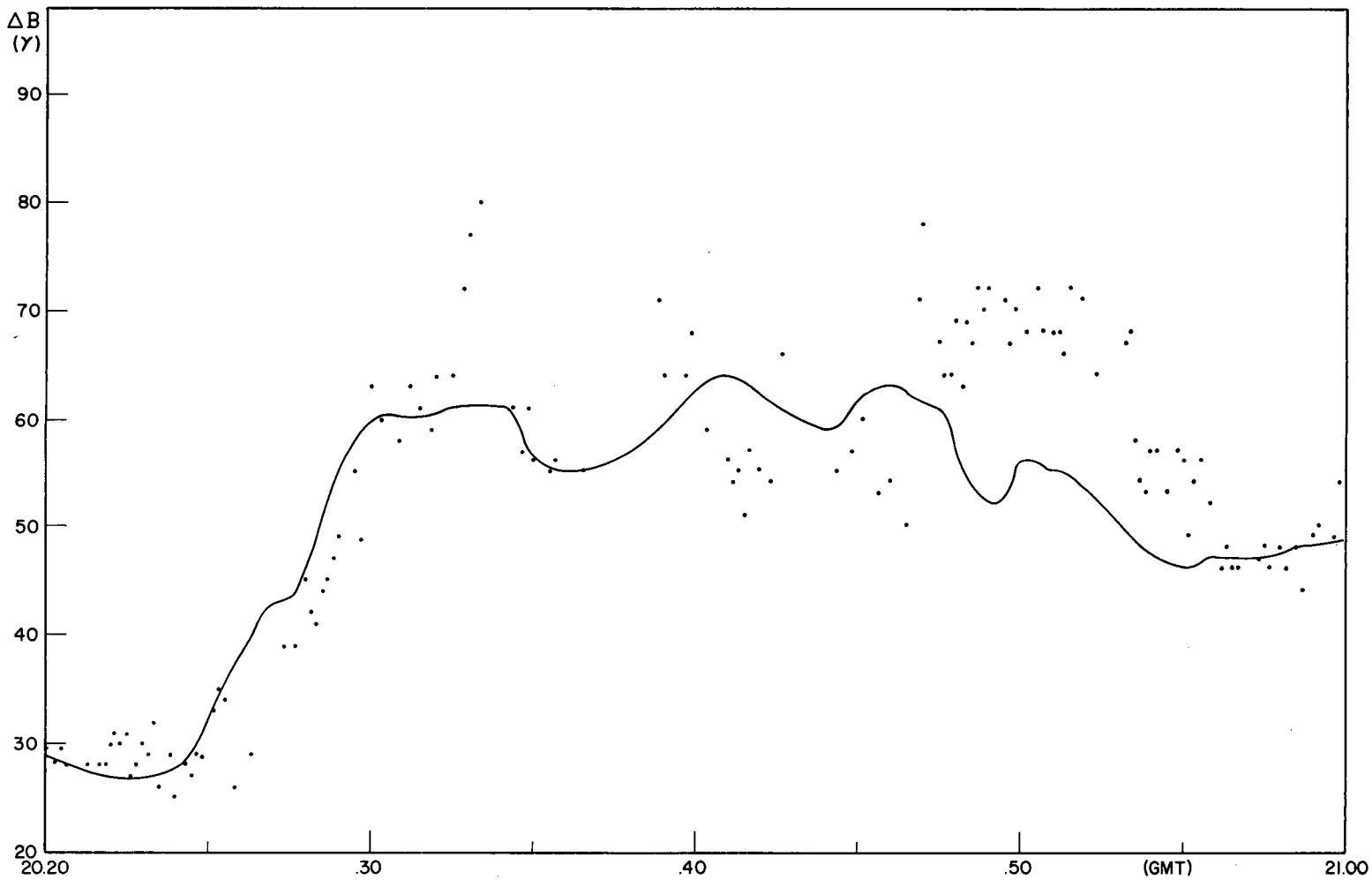

ΔB
(γ)
90
80
70
60
50
40
30
20
20.20
.30
.40
.50
(GMT)
21.00
DECEMBER 1, 1961. LAT. -10°, LONG. 125°, DIST. 76X10³ KM., J.C. FIELD 22γ AT 20.25 GMT
Explorer XII ..... LT = GMT +8h
Honolulu ——— LT = GMT -11h

Figure 7

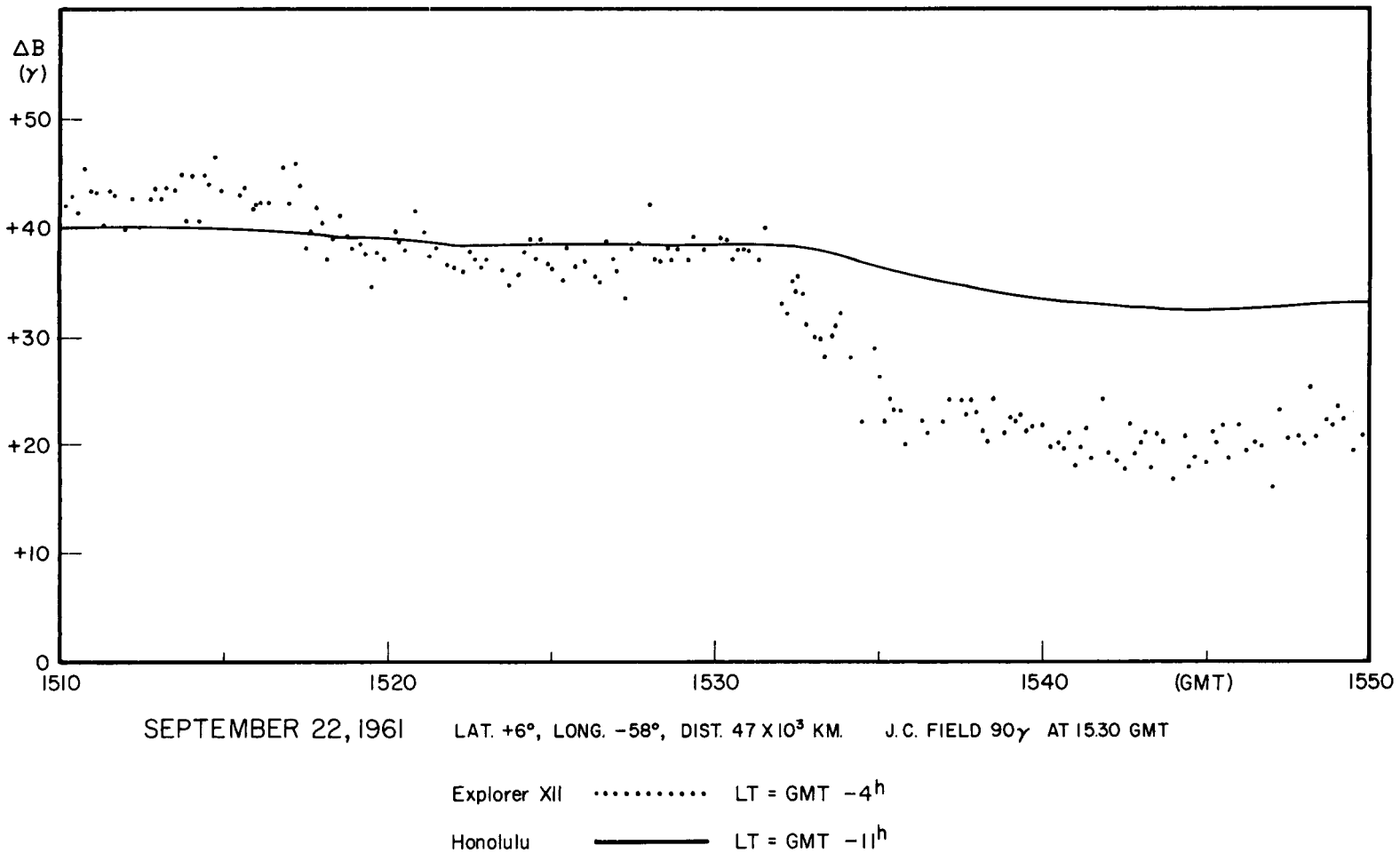
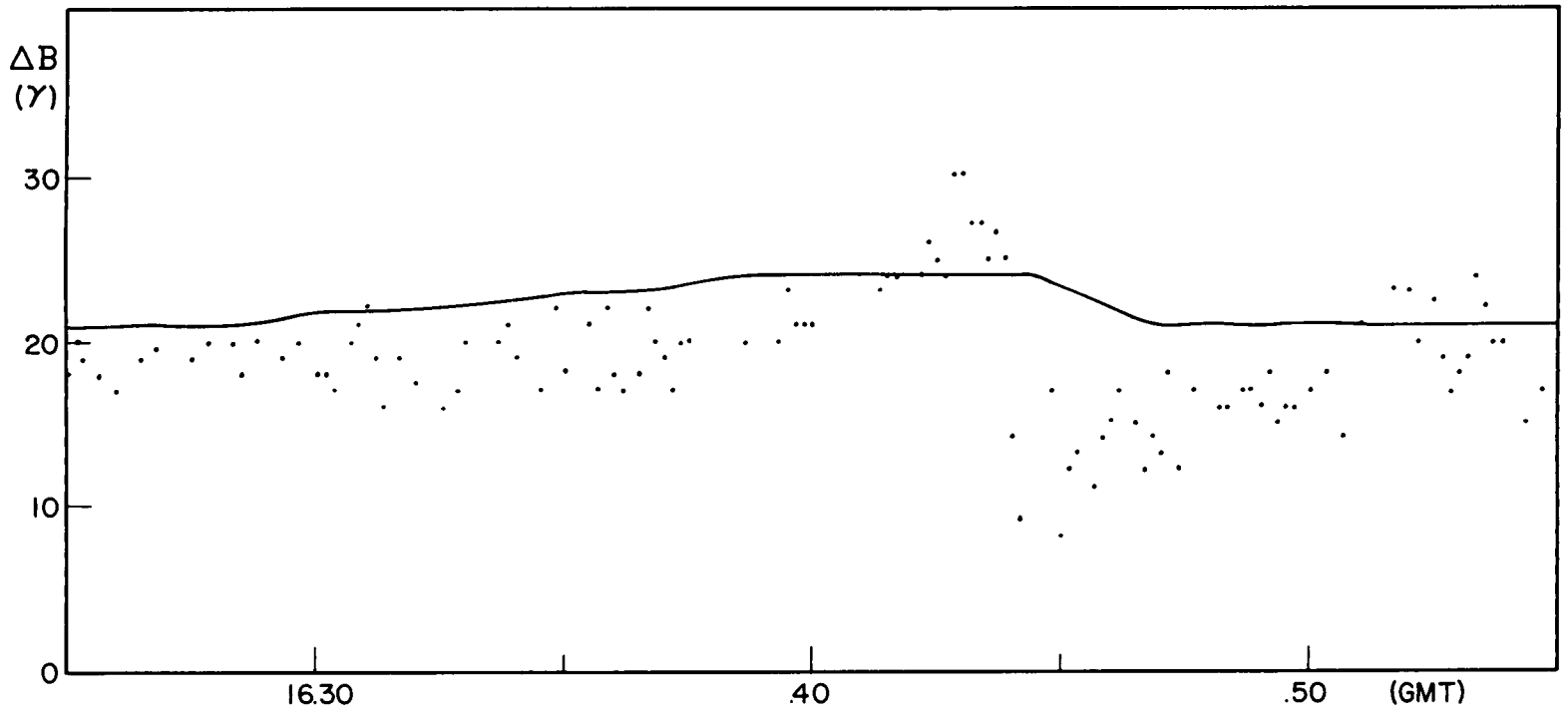

ΔB
(γ)
+50
+40
+30
+20
+10
0
1510
1520
1530
1540
(GMT)
1550
SEPTEMBER 22, 1961
LAT. +6°, LONG. −58°, DIST. 47 X 10³ KM.
J.C. FIELD 90γ AT 1530 GMT
Explorer XII
LT = GMT −4h
Honolulu
LT = GMT −11h

Figure 8



OCTOBER 8, 1961 LAT. −12°, LONG. −123°, DIST. 80X10^{3}KM., J.C. FIELD 16γ AT 16.45 GMT

Explorer XII ..... LT = GMT −8^h

Honolulu ——— LT = GMT −11^h

Figure 9

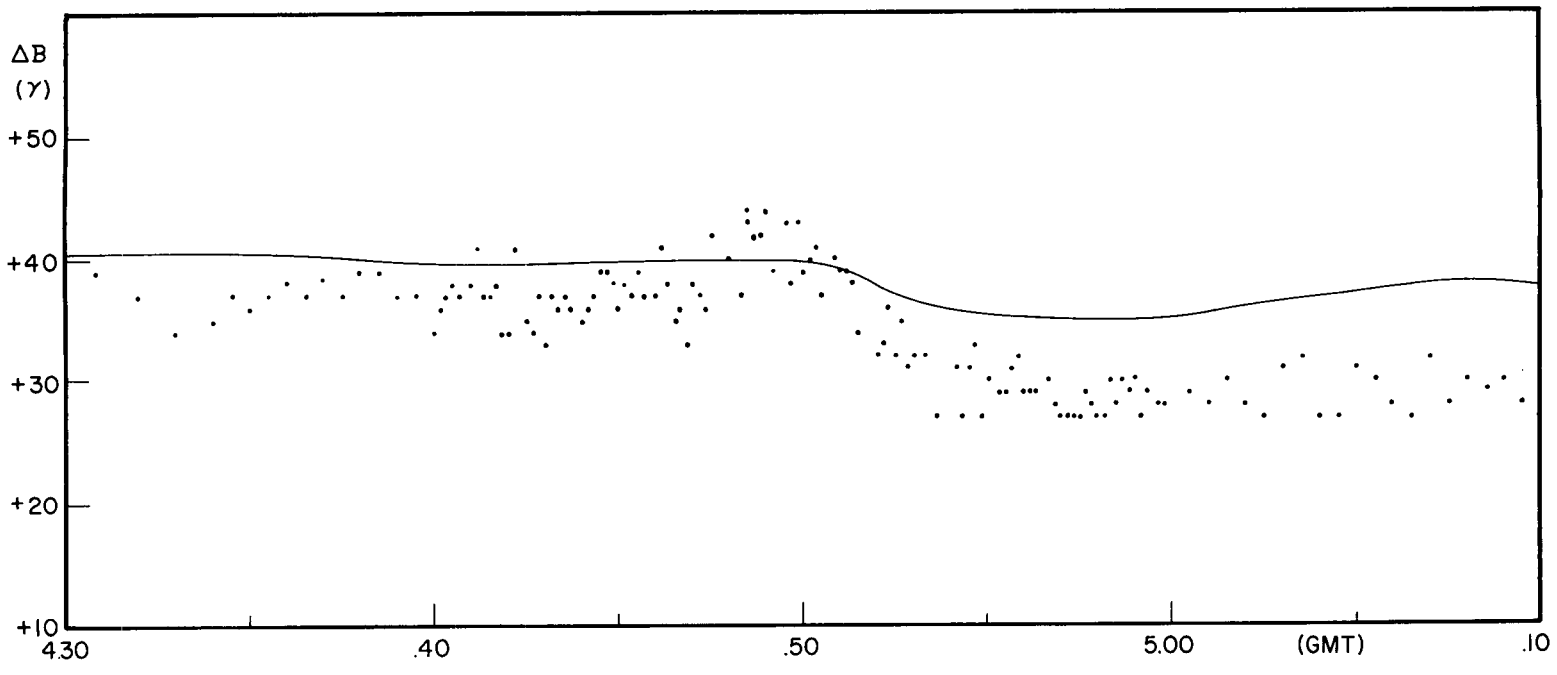

ΔB
(γ)
+50
+40
+30
+20
+10
4.30
.40
.50
5.00
(GMT)
.10
OCTOBER 9,1961
LAT. +4°, LONG. +81°, DIST. 55X10³KM.
J.C. FIELD 90γ AT 4.50 GMT
Explorer XII
LT = GMT +5h
Honolulu
LT = GMT -11h

Figure 10

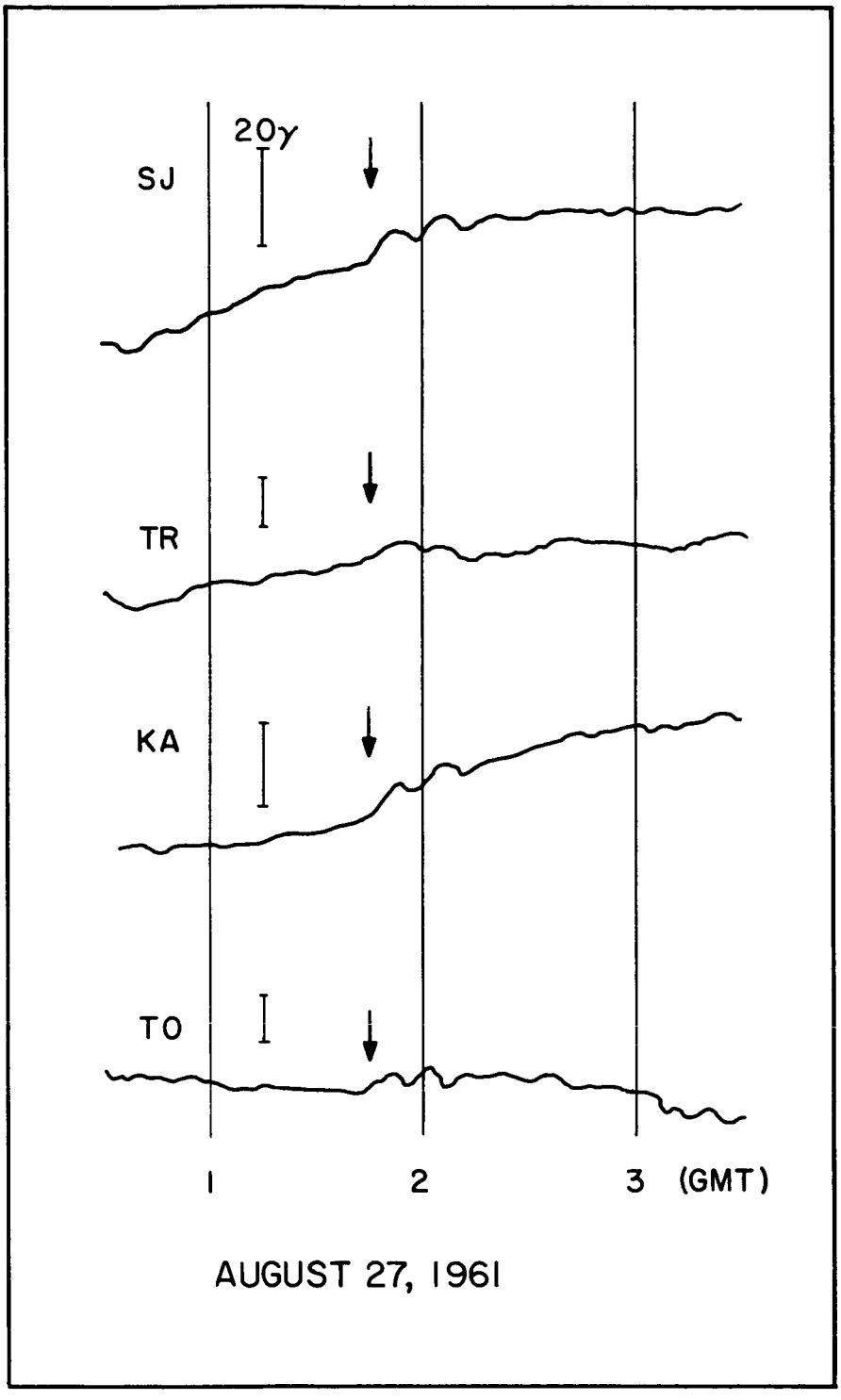


Figure 11

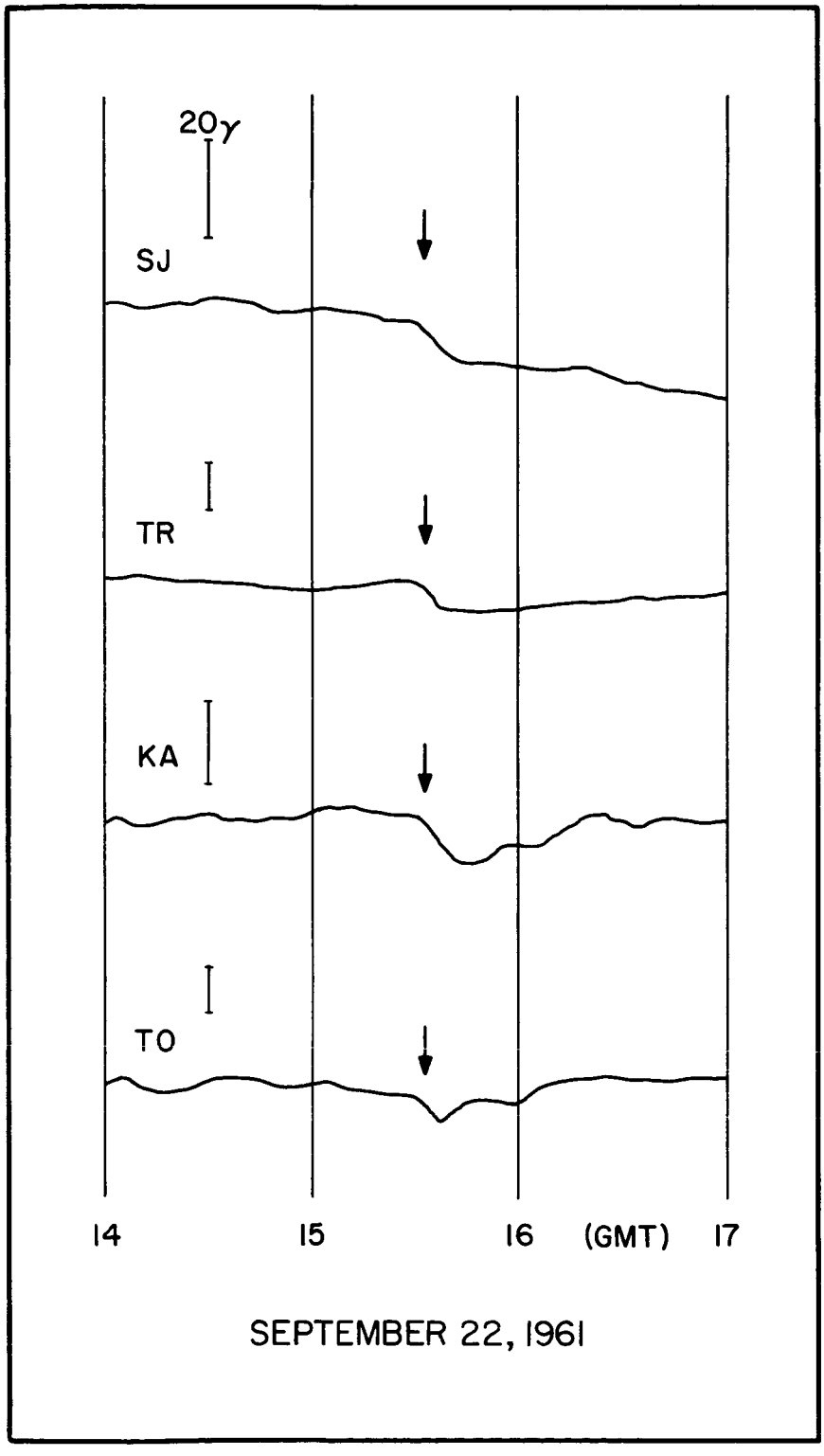


Figure 12

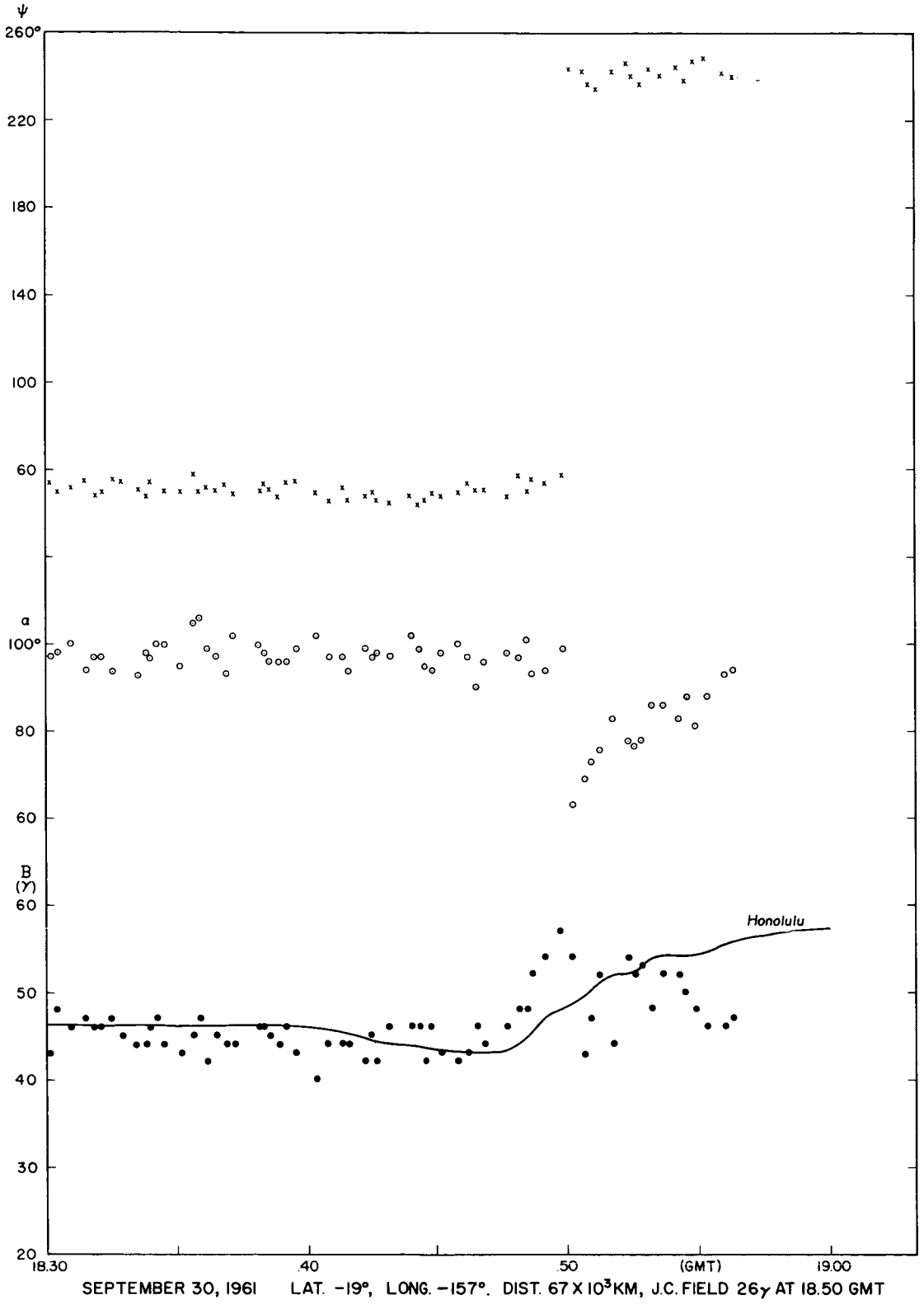
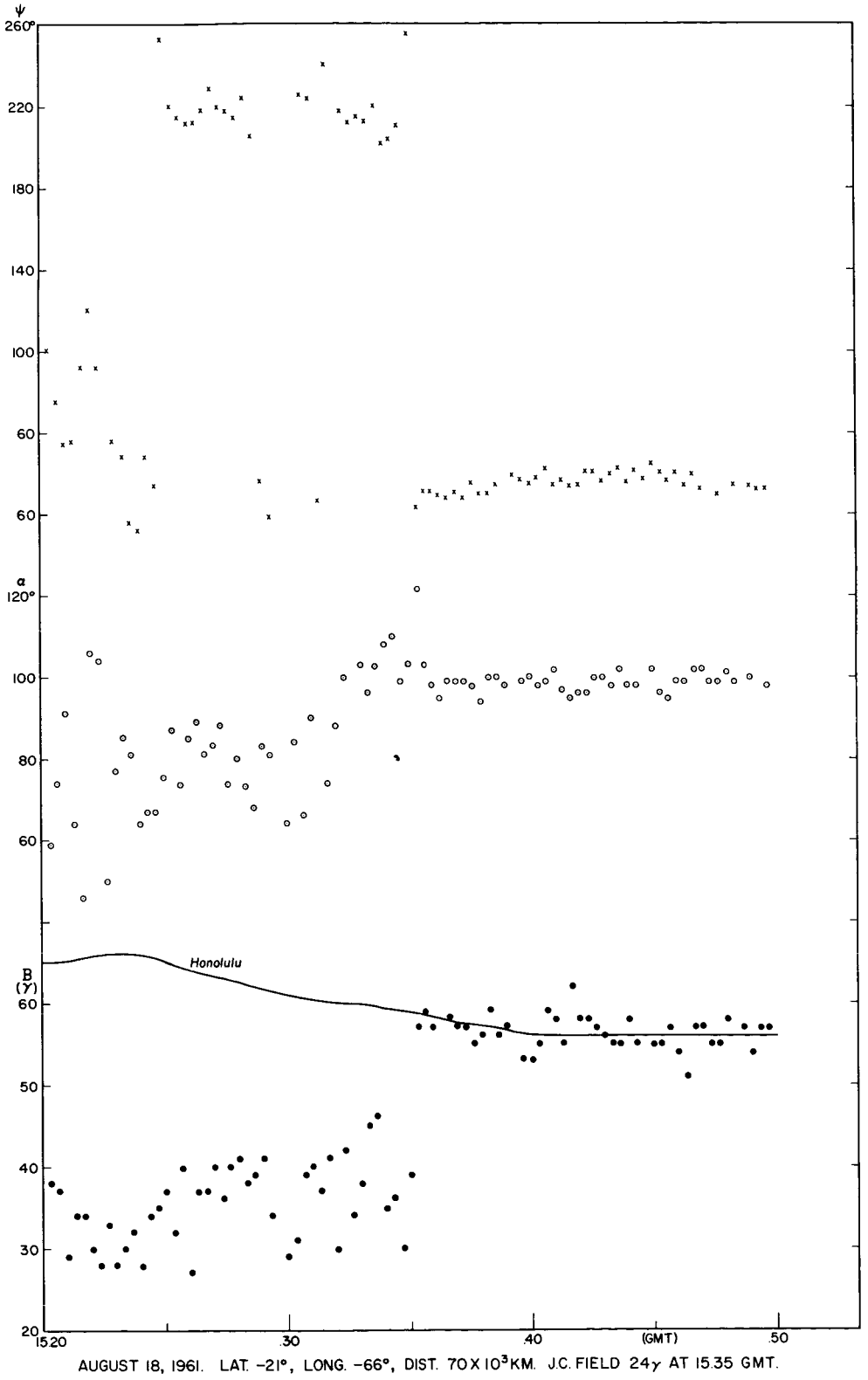

ψ
260°
220
180
140
100
60
α
100°
80
60
B
(γ)
60
50
40
30
20
Honolulu
18.30
.40
.50
(GMT)
19.00
SEPTEMBER 30, 1961 LAT. -19°, LONG. -157°. DIST. 67 X 10³KM, J.C. FIELD 26γ AT 18.50 GMT

Figure 13



AUGUST 18, 1961. LAT. -21°, LONG. -66°, DIST. 70 X 10^3 KM. J.C. FIELD 24γ AT 15.35 GMT.

Figure 14

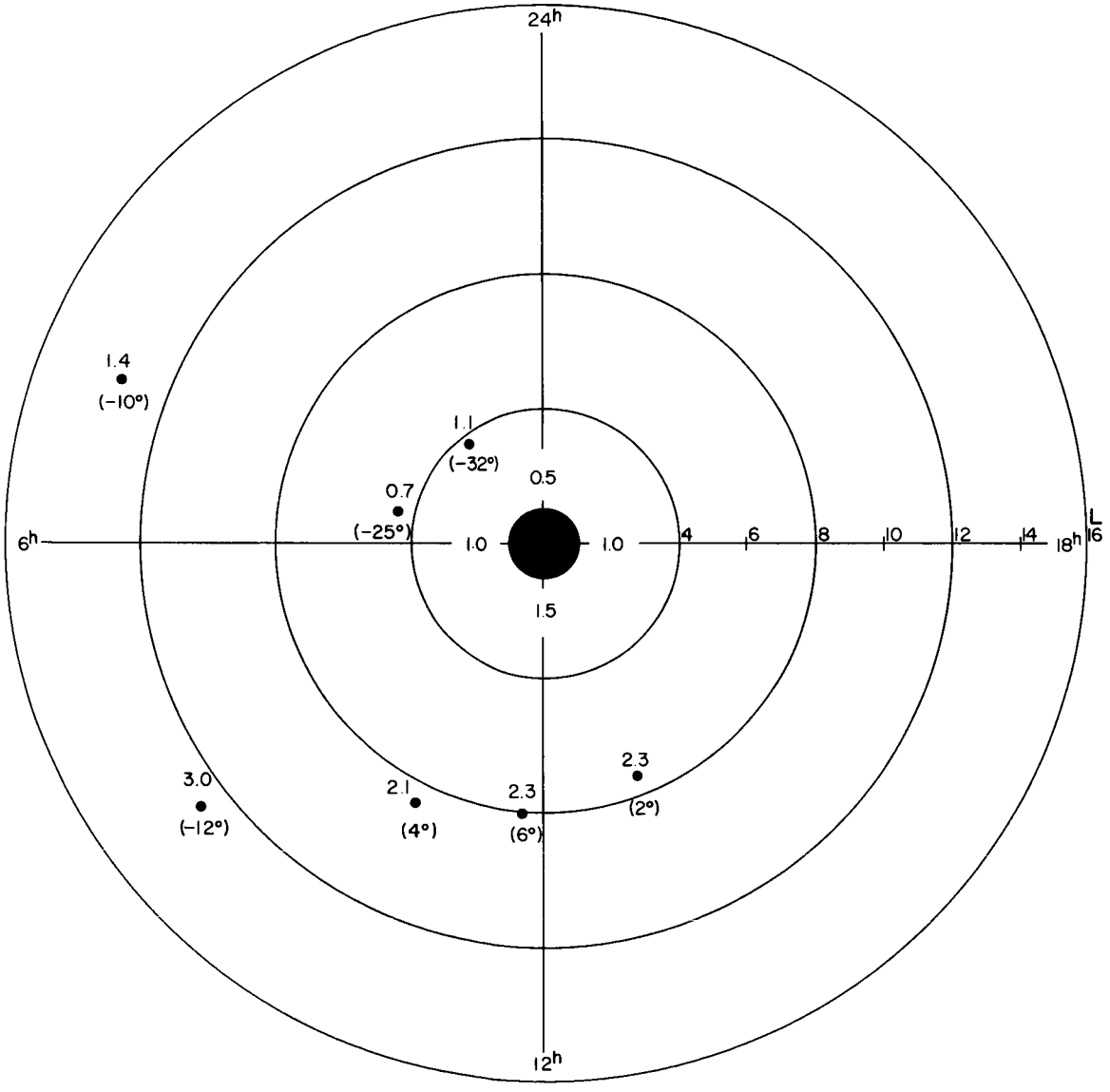

24h
12h
6h
18h
L
4
6
8
10
12
14
16
1.0
1.0
0.5
1.5
1.4
(-10°)
1.1
(-32°)
0.7
(-25°)
3.0
(-12°)
2.1
(4°)
2.3
(6°)
2.3
(2°)

Figure 15